# PUPILLARY SIZE CHANGE AS CORRELATED WITH MENTAL ACTIVITY

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# THESIS

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Pupillary Size Change
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Correlated with Mental Activity

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ABSTRACT

An indirect measurement of mental activity was correlated with changes in pupil size during simple multiplication solving. There was also a close correlation between mental activity and the difficulty of the problem. With an increase in difficulty, there was an associated increase in pupil size for correctly answered problems, but an associated decrease in pupil size for wrong replies.

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# I. INTRODUCTION

The changing of pupil sizes has been acknowledged for some time as a clue to emotions or qualities which have nothing to do with vision, per se.

It is said that Chinese jade dealers will watch a purchaser's pupil for an indication of satisfaction with a particular piece of jade in hopes that the buyer will pay a higher price. The card-trick magician also watches the eyes of the person who is thinking about a certain card and is able to identify it by watching the eyes dilate.

Guillaumo de Salluste poetically expressed the eyes as: "These lovely lamps, the windows of the soul." The eye is mentioned in everyday usage to connote some types of emotion, such as "beady-eyed," "bug-eyed," "hard-eyed," "soft-eyed," or expressions like "his eyes were pinpoints of hate," or "his eyes were like saucers." Even Charles Darwin in his Expressions of Emotion in Man and Animal, equated human emotions with movements of the eyelids and eyebrows, but it is assumed that he equated dilation and constriction of the pupil as an involuntary reflex to changes in light intensities.

The autonomic nervous system is separated into two divisions: the parasympathetic and the sympathetic. Pupil size adjustment or the physiological mechanism that responds to light intensities is controlled by the parasympathetic (involuntary) division.

The role of the sympathetic division is more complex but there is an increasing amount of evidence, especially within the past ten years, that the size of pupils is directly proportional to certain activities of this division within the nervous system.

Kuntz (1929) discussed the parasympathetic division with respect to light reflex but mentions the sympathetic division when he points out that "strong emotional states are accompanied by general sympathetic stimulation," and that "deep emotions of pleasure as well as fear are commonly accompanied by pupillary dilation."

Perhaps one of the earliest papers that indicated that pupil size might be an index of the activity of the nervous system was Bumke (1911). He reported on two previous experimenters that observed the eyes of subjects undergoing mental activity and saw gross changes in pupil size that correlated with the mental activity.

Prior to the last decade, many experiments were conducted utilizing the galvanic skin response as a physiological measurement but not until circa 1960 were there major efforts to use pupil size change as a corroborative measurement.

Hess and Polt (1960) described the methods and results of a study employing two females and four males. Having previously observed that a cat's pupils dilate when it is presented with (a) a strange cat, (b) a familiar play object, (c) a familiar food and (d) an unfamiliar food (especially after the scent had been perceived), the two psychologists explored the idea that changes in pupillary size

of human subjects might constitute a "measure of greater or less interest value and pleasure value of visual stimuli."

The experimenters used five stimulus pictures and took 16-millimeter moving pictures of the subjects' one eye. The pictures, one frame at a time, were projected at a constant ratio of enlargement and the diameter of the pupil's image was measured with a ruler. The "before" measurements were converted into area as were the "during" measurements to compute the percentage change in area attributable to that stimulus, trial and subject. It should be noted that many experimenters are reporting their findings in percentage change in diameter vice area.

The result of Hess and Polt's experiment were published in graphic form showing the mean percentage of increase in pupil area for each picture and each sex. The table below has converted those results into percentages and then ranked them.

| STIMULUS PICTURE | 4 MALES | | 2 FEMALES | |
|---|---|---|---|---|
| | % | Rank | % | Rank |
| Partially nude female | 18 | 1 | 5 | 4 |
| Partially nude male | 7 | 2 | 20 | 2 |
| Mother and child | 5 | 3 | 25 | 1 |
| Landscape | 2 | 4 | -7 | 5 |
| Baby | 0 | 5 | 17 | 3 |

No attempt was made to explain the seven percent reduction among the females viewing the landscape. Hess and Polt interpret these results as "a clear dichotomy in regard to the interest value of the pictures" for the different sexes as shown by the responses to the nude pictures and the mother and child picture.

A later experiment conducted by Hess and Polt (1964) applied similar measurement methods of pupil size changes to five subjects while they solved four "mental arithmetic" problems of presumably increasing difficulty. The problems and answers were given orally while each subject fixated on the figure "5" which was projected on the center of a screen.

The ostensible reason for this fixation procedure was to keep the subject's eyes properly positioned and illuminated by a standard 100-watt light bulb. The figure "5" was considered irrelevant to the mental tasks employed since it remained a constant visual stimulus.

The results obtained always showed an increase of dilation for each problem of increasing difficulty. The overall mean percentage increase in pupil diameter and each problem were shown to be:

| | Problems in Order of Presentation | | | |
|---|---|---|---|---|
| | 7 x 8 | 8 x 13 | 13x14 | 16x23 |
| Overall Means: | 10.8% | 11.3% | 18.3% | 21.6% |

In a third comprehensive article, Hess (1965) discusses the discrimination between positive and negative affects as a two-directional method of measuring pupillary changes and summarizes much of the two experiments reviewed above. It extends the method to other stimuli and to senses other than sight. It also suggests application to esthetics, attitude assessment and change, decision making, the measurement of stress, psychotherapy, market and product research, a child's degree of "identification" with his parents, the development of sexual interests in adolescence, etc.

The report stated that unpleasant stimulus pictures produced marked decreases in pupil size. The subjects responded negatively (pupil constriction) to pictures of crippled or cross-eyed children, sharks and dead bodies. Hess states:

> Although we have delt primarily with positive stimuli, the evidence suggests that at least with respect to visual material there is a continuum of responses that ranges from extreme dilation for interesting or pleasing stimuli to extreme constriction for material that is unpleasant or distasteful to the viewer. In the presence of uninteresting or boring pictures we find only slight random variations in pupil size.

In light of the three experiments previously discussed, this author attempted to expand on Hess and Polt's second experiment. Since no mention was made of incorrect replies, it was hypothesized their results, as shown on page 9, were obtained from data collected on subjects who correctly computed the problems.

Therefore, an exper ment was devised, utilizing the same problems as were used by Hess and Polt, to observe whether pupils always dilate regardless of the correctness of the solution; or, would an antithesis occur between the correct and incorrect solutions.

## II. EXPERIMENTAL PROCEDURE

The method of obtaining pupillary measurements was accomplished by direct readings of pupil diameter from a chart recorder.

The chart recorder is an integrated system of a television pupillometer (Appendix A) capable of continuous, real time measurement of pupil diameters in an interval of five millimeters within a range from zero to ten millimeters (normal pupil diameters range from 2.9 to 6.5 mm.).

The pupillometer utilizes a closed circuit television focused on the subject's eye which is illuminated by a low-intensity, near infrared source. This light source illuminates the eye without discomfort or distraction to the subject under test, as well as producing the necessary signal that is electronically processed to measure and display the pupil diameter.

While being introduced to the equipment, each subject was briefed that he would be required to do a series of four multiplication problems during the experiment. This introduction period accomplished (1) an attempt to put the subjects at ease and make them feel more comfortable with the pupillometer and (2) an acclimation of the eyes to the comparatively dim light intensities (the equipment and subjects were located in one corner of a room surrounded by quasi-blackout curtains).[1]

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[1] All experiments were conducted at the U. S. Naval Postgraduate School's Human Engineering Laboratory, Monterey, California

The subject was then requested to place his head in a standard, curved and padded, metal head holder, placing his chin on the accompanying, adjustable, chin rest. After the subject was comfortably positioned, he was requested to fixate upon a push-tack anchored upon the wall, approximately one and one-half meters in front of his eyes. At this time, the television camera was adjusted and focused on the left eye to provide an optimum position for recording the pupil diameters.

The use of a fixation target provided a constant distance for the subject's eyes; therefore, neither that constriction of the pupil which accompanies a shift in eye focus from a far to a near object, nor the dilation which accompanies a shift from near to far, was represented in the data gathered.

Also, the fixation target was kept at a constant illumination throughout the test session to realize a twofold purpose: (1) parasympathetic pupillary reflex to mere changes in brightness could be ruled out, and (2) to provide an even environment for a baseline of pupillary size from which to measure changes attributable to the problem-solving stimulus.

Therefore, the visual field was held constant and accommodation was not a factor. Auditory stimulation was held to the experimenter's voice giving the problems and the continuous sound of the chart recorder.

Prior to any request for problems a thirty-second period was recorded to provide a baseline of pupil diameter. The subject was presented the first problem: "multiply seven times eight." A ten second delay was incorporated between every answer and the subsequent: "multiply eight times thirteen," "multiply thirteen times fourteen," and finally "multiply sixteen times twenty-two." The test was terminated ten seconds after each subject's last reply.

The subject was informed after each answer whether his mental problem solving was correct or not.

Quantification of pupillary change was accomplished by observing the actual pupil diameter as recorded on the heat-sensitive graph paper. The diameter reading at the point prior to posing the question and the point prior to the subject uttering the answer were recorded for data. The diameter, prior to posing the question, was subtracted from the diameter, prior to uttering the answer, and the difference was then divided by the prior-to-posing-the-question diameter to compute the percentage change in diameter attributable to that problem and subject.

## III. DISCUSSION AND RESULTS

As this experiment was analogous to the one conducted by Hess and Polt (1964), it was not the intention of this author to plagiarize but to extend their experiment. In the description of their design, they stated the subjects were told whether the answers were correct or not; however, no results relevant to the wrong answers were reported.

It was the objective of this experiment to test this author's hypothesis that the pupils will constrict if wrong answers are given. A second objective for the author was to test the performance of the newly acquired television pupillometer; therefore, a simple, easily verified experiment was in order.

The resulting percentage changes in pupil diameter are recorded in Table I.

TABLE I.

PERCENTAGE OF CHANGE IN PUPIL DIAMETER

The diameter was measured at the point prior to posing the problem and compared to the diameter prior to the subject uttering the answer.

| SUBJECT | PROBLEM 7x8 | 8x13 | 13x14 | 16x23 |
|---|---|---|---|---|
| 1 | 13.3 | 15.7 | 18.2 | -2.7 |
| 2 | 13.7 | 7.4 | 16.6 | 20.1 |
| 3 | 8.5 | 12.6 | 19.2 | 20.6 |
| 4 | 8.0 | 12.0 | -12.2 | -20.1 |
| 5 | 8.6 | 16.6 | - 2.5 | - 7.5 |
| 6 | 28.2 | 56.6 | -14.7 | -17.7 |
| 7 | 16.6 | 21.6 | 23.4 | 25.2 |
| 8 | 5.9 | - 3.6 | - 1.8 | 20.4 |
| MEANS: | 12.85 | 17.36 | 5.78 | 4.79 |

The Kendal rank correlation coefficient procedure was used to find the degree to which the means of Table I and the means of Hess and Polt (1964) agree. The computed TAU found the correlation to be -0.66 [Siegel 1965].

It was interesting to note, that upon dichotomizing the data into correct replies and incorrect replies the Kendal rank correlation proved perfect agreement between the means of the correct replies of this experiment and the means obtained by Hess and Polt. However, when the means obtained by Hess and Polt were correlated with the means of the wrong answers of this experiment, perfect disagreement was found. Table II and Table III show the results of dichotomizing the replies.

TABLE II

PERCENTAGE CHANGE OF PUPIL DIAMETER FOR CORRECT REPLIES

| SUBJECT | PROBLEM | | | |
|---|---|---|---|---|
| | 7x8 | 8x13 | 13x14 | 16x23 |
| 1 | 13.3 | 15.7 | 18.2 | --- |
| 2 | 13.7 | --- | 16.6 | 20.1 |
| 3 | 8.5 | 12.6 | 19.2 | 20.6 |
| 4 | 8.0 | 12.0 | --- | --- |
| 5 | 8.6 | 16.6 | --- | --- |
| 6 | --- | --- | --- | --- |
| 7 | 16.6 | 21.6 | 23.4 | 25.2 |
| 8 | 5.9 | --- | --- | 20.4 |
| MEANS: | 10.66 | 15.70 | 19.35 | 21.58 |

TABLE III

PERCENTAGE CHANGE OF PUPIL DIAMETER FOR INCORRECT REPLIES

| SUBJECT | PROBLEMS | | | |
|---|---|---|---|---|
| | 7x8 | 8x13 | 13x14 | 16x23 |
| 1 | --- | --- | --- | - 2.7 |
| 2 | --- | -7.4 | --- | --- |
| 3 | --- | --- | --- | --- |
| 4 | --- | --- | -12.2 | -20.1 |
| 5 | --- | --- | - 2.5 | - 7.5 |
| 6 | 28.2 | 56.6 | -14.7 | -17.7 |
| 7 | --- | --- | --- | --- |
| 8 | --- | - 3.6 | - 1.8 | --- |
| MEANS: | 28.20 | 20.13 | - 7.8 | -12.00 |

Pupil size typically reached a peak (either positive or negative) prior to verbalizing the answer. While uttering the reply, the chart recorder would go off scale, the same as for eye blinks, due to the subject's chin resting on the head mount. As he verbalized, the chin would move the head and the eye would move out of the optimum viewing position; thus, the basis behind recording the data just before the subject would verbalize. The mental activity was present, he only needed to vocalize it.

Inspection shows for Table II that each individual's percentages tended to rank the four problems in the relative same order. The more difficult the problem, the larger the pupil became as the solution was reached. After each answer was given, there was an immediate drop in pupil diameter, then a slow, but steady decrease to a control level. These results showed evidence that pupil size is highly correlated with intensity of mental activity. However, it is also theorized the results reflected a positive affect, as discussed by Hess (1965).

Perhaps the pupil dilation represented the subject's pride when he realized he had obtained a solution and that his pride or pleasure increased with solving a more difficult problem than an easier one.

Inspection shows for the incorrect answers that each individual's percentages also tended to rank the four problems in the relative same order, but in complete reversal to the rankings for the correct replies. Only one subject, number eight, showed a small increase in diameter, which occurred between neighboring problems. After each problem was posed, the pupil diameter increased to a maximum point. For problems one and two (subject eight being an exception), the diameter did not increase but maintained the maximum level. This dilation was interpreted as a measure of increased mental activity as well as a positive affect, since it was believed that the subjects felt their solutions to be correct. (Subject eight's pupils constricted and he stated he knew his solution was wrong.) However, for problems three and four, the diameter decreased after the "maximum-point" and continued to decline through the base-line and into the constriction region, before the answers were verbalized. This dilation and subsequent constriction was interpreted as a very complex physiological action taking place within the subjects' sympathetic nervous system.

The sympathetic stimuli were felt to be the mental activity of the subjects attempting their computation (dilation) and the subsequent realization their solutions were incorrect (constriction). The constriction was considered to be solely due to a negative affect and was

partially interpreted as a reflection of the subject's "disgust" in missing the correct solution.

To complete the interpretation of this negative affect, an analogy is drawn. For example, when a person suffers cerebral anemia, his body undergoes a transient form of unconsciousness to relax the body and allow free movement of the needed blood back to the brain. As fainting tries to exclude external stimuli, an overworked brain constricts the pupils in an attempt to block out visual stimuli and give the brain a "rest." Therefore, it was conjectured the mind was overworked and the subjects disliked the mental gymnastics. This "mental-block" which increased the negative affect and correspondingly decreased the mental activity was realized as pupil constriction.

Subject six's replies were all incorrect and during the instruction period, she had stated that her multiplication ability was very poor. She was nervous and quite jittery while trying to answer each question and for problems three and four, no answers were given. Even omitting subject six's data from Table III, a correlation of those ranked means with the ranked means obtained by Hess and Polt (1964) was still -1.00.

The experiment showed mental activity, with its positive and negative affects, can be indirectly measured as a result of pupillary changes. For correctly computed problems, increased pupil diameter occurred with increased mental activity as the degree of difficulty of the problems increased. For incorrectly computed problems, a

decrease in pupil size was realized as a result of decreased mental activity and the diameter continued to decrease as the degree of difficulty of the problem increased.

As previously mentioned, the second objective was to test the performance of the pupillometer. The results obtained showed the instrument was giving correct readings; however, it was necessary to calibrate the chart recorder prior to every subject. More than once, a subject had to be excused from the experiment because the heat pens increased their tensions and began sticking to the paper, thereby losing calibration.

After learning to operate the pupillometer and its associated equipment, it was a very easy, one-man task to monitor and record a subject's pupil size. It is indeed, a very big improvement over the crude, pupil-response "box" as used by Hess (1965).

Further experiments that might be profitably studied on the pupillometer are the differences between the kind of data generated by measures of pupillary size change (PSC) and measures of galvanic skin response (GSR) in an attempt to further quantify the physiological con-concomitants of positive and negative affects. Also, one might investigate what would happen to pupil size if visual and auditory stimuli were to occur simultaneously, or, perhaps a combination of visual, auditory and olfactory stimuli.

It must be pointed out that mental activity and physiological affects are very complex processes that are not fully understood by today's

physiologists and psychologists, but as men continue with experiments such as these, it is hoped that God's creation, man, may be better understood.

## APPENDIX A. FIGURES

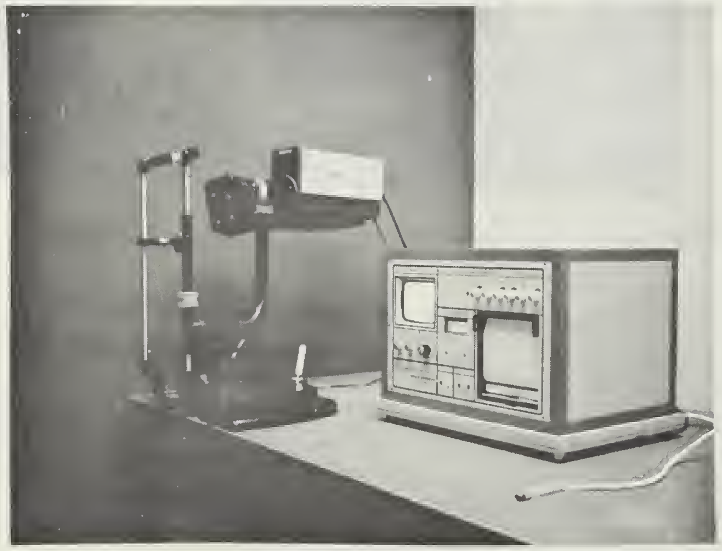

FIGURE 1. THE TELEVISION PUPILLOMETER

The Space Science Incorporated TV Pupillometer, Model 831D, is capable of real-time measurement and display of the absolute diameter of the pupil. The dual-channel chart recorder incorporates permanent, simultaneous recordings of pupil dynamics on the left and of external data on the right.

FIGURE 2. PUPILLOMETER IN USE

Notice the television picture of the subject's pupil.

FIGURE 3. PUPILLOMETER IN USE

Notice the picture, panel meter and chart recorder showing pupil diameter.

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13. ABSTRACT

An indirect measurement of mental activity was correlated with changes in pupil size during simple multiplication solving. There was also a close correlation between mental activity and the difficulty of the problem. With an increase in difficulty, there was an associated increase in pupil size for correctly answered problems, but an associated decrease in pupil size for wrong replies.

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| Pupillometer | | | | | | |
| Eye (pupil) | | | | | | |
| Human Engineering (pupil) | | | | | | |
| Human Factors (pupil) | | | | | | |